

BMW: a ROSAT-HRI Source Catalogue Obtained with a Wavelet Transform Detection Algorithm

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Abstract. In collaboration with the Observatories of Palermo and Rome and the SAX-SDC we are constructing a multi-site interactive archive system featuring specific analysis tools. In this context we developed a detection algorithm based on the Wavelet Transform (WT) and performed a systematic analysis of all ROSAT-HRI public data (~ 3100 observations + 1000 to come). The WT is specifically suited to detect and characterize extended sources while properly detecting point sources in very crowded fields. Moreover, the good angular resolution of HRI images allows the source extension and position to be accurately determined.

This effort has produced the BMW (Brera Multiscale Wavelet) catalogue, with more than 19,000 sources detected at the $\sim 4.2\sigma$ level. For each source detection we have information on the position, X-ray flux and extension. This allows for instance to select complete samples of extended X-ray sources such as candidate clusters of galaxies or SNR's. Details about the detection algorithm and the catalogue can be found in Lazzati et al. 1999, Campana et al. 1999 and Panzera et al. 2001. Here we shall present an overview of first results from several undergoing projects which make use of the BMW catalogue.

1 The Catalogue

The wavelet detection algorithm (WDA) we developed was made suited for a fast and efficient analysis of images taken with the ROSAT HRI instrument (see Lazzati et al. 1999 and Campana et al. 1999). From the automatic analysis of all pointing observations available in the ROSAT public archive (at HEASARC and MPE) as of January 1999, we derived the BMW catalogue with sources detected with a significance $\sim 4.2\sigma$ (~ 19000). All the detected HRI sources are characterized in flux, size and position. In Fig. 1 we show the differential and integral distributions of exposure times and galactic absorptions; while in Fig. 2 we plot the results of source detection applied to the crowded Trapezium field. At variance with the “sliding box” detection algorithms the WDA provides also a reliable description of the source extension allowing for a complete search of e.g. supernova remnants or clusters

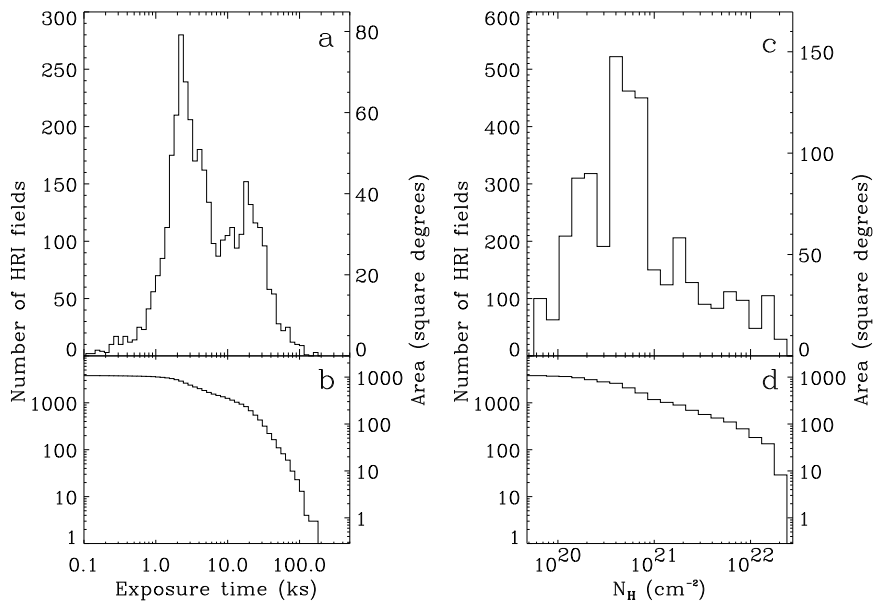


Fig. 1. (a) Distribution of the HRI exposure times of the HRI images (all but SNR and calibration fields) that we have analyzed; (b) cumulative distribution. (c) Distribution of the Galactic column density in the same fields; (d) cumulative distribution.

of galaxies in the HRI fields. To assess the source extension we considered all the sources detected in the observations that have a star(s) as a target (ROR number beginning with 2): 6013 in 756 HRI fields. The distribution of the source width (σ) as a function of the source off-axis angle has been divided into bins of 1 arcmin each in which we applied a σ -clipping algorithm on the source width. This method iteratively discards truly extended sources and provides the mean value of σ for each bin. We then determined the 3σ dispersion on the mean for each bin. The mean value plus the 3σ dispersion provide the threshold for the source extension (*dashed line* in Fig. 3; see also Rosati et al. 1995). We conservatively classify a source as extended if it lies more than 2σ from this limit (*filled squares* in Fig. 3).

More than 1000 new HRI fields have been taken from the ROSAT public archive and will be analyzed in the next future.

2 First Results

In the following we present the first results obtained using the BMW catalogue.

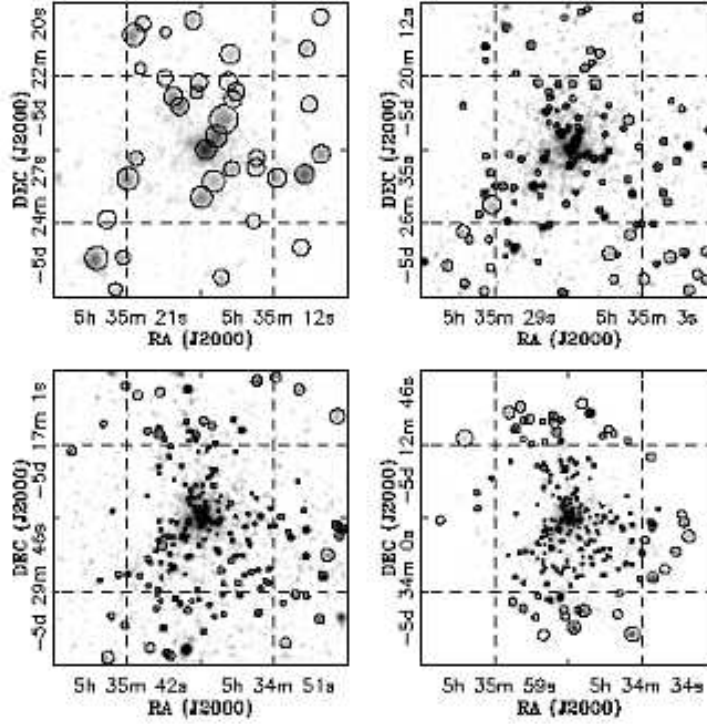


Fig. 2. Source detection in the Trapezium field. The four panels show the smoothed images at rebin 1, 3, 6 and 10 (i.e. pixel size of 0.5, 1.5, 3.0 and 5 arcsec, respectively), respectively. Circles mark X-ray sources; the size of the circles is twice the source width (σ ; modeled as a Gaussian).

2.1 Search for Periodic Signals

The BMW catalogue contains about 3000 sources with more than 160 photons, which we set as the minimum number required to carry out a meaningful search for periodic signals (see Israel et al. 1998). In collaboration with the Osservatorio Astronomico di Roma, these light curves were analyzed in a systematic way by using the algorithm of Israel & Stella (1996) for the detection of coherent or quasi-coherent signals in the power spectra even in presence of additional non-Poissonian noise components. The technique was modified to correct for the spurious effects which characterise the ROSAT light curves. During this systematic search we discovered ~ 321 s pulsations in the X-ray flux of 1BMW J080622.8 +152732 = RX J0806.3+1527 (Fig. 4).

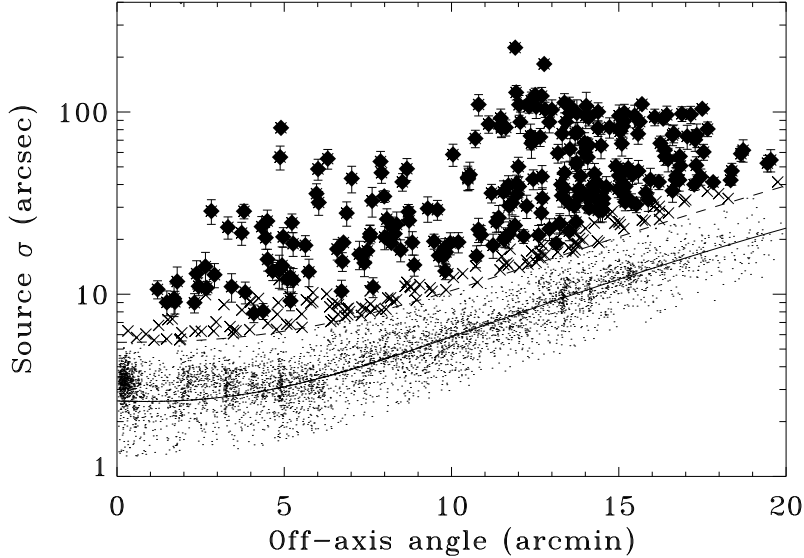


Fig. 3. Source extension (σ) vs. off-axis angle for 6013 sources detected in the HRI fields pointed on stellar targets. *Dashed line*, marks the 3σ extension limit for point-like sources; *solid line*, computed PSF.

Two different HRI observations were obtained with the source at flux level of 3 and $5 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$, respectively. Only a faint $B = 20.5$ object is present within the error circle, while no optical counterpart is present in the R plate down to a limiting magnitude of ~ 20 . This indicates that the object is intrinsically blue. The X-ray and optical findings imply that the source is a relatively distant ($\sim 500 \text{ pc}$) isolated white dwarf or, a nearby ($\sim 10 \text{ pc}$) isolated neutron star accreting from the interstellar medium (Israel et al. 1999; Israel et al. 2001).

2.2 Search for Clusters of Galaxies

The evolution of the abundance of massive clusters of galaxies represents a key test for the models of large-scale structure formation. X-ray observations are the most fruitful (and physically sound) way to find such objects at high redshift ($z > 0.5$), as demonstrated in recent years by surveys based on the ROSAT PSPC archival data (e.g. Rosati et al. 1998, Vikhlinin et al. 1998a). On the contrary, the ROSAT HRI data archive received poor attention as a source for cluster searches, due to its lower sensitivity and higher background. Our first results on BMW cluster candidates are showing that these problems can be overcome with a clever analysis of the data (see Campana et al. 1999).

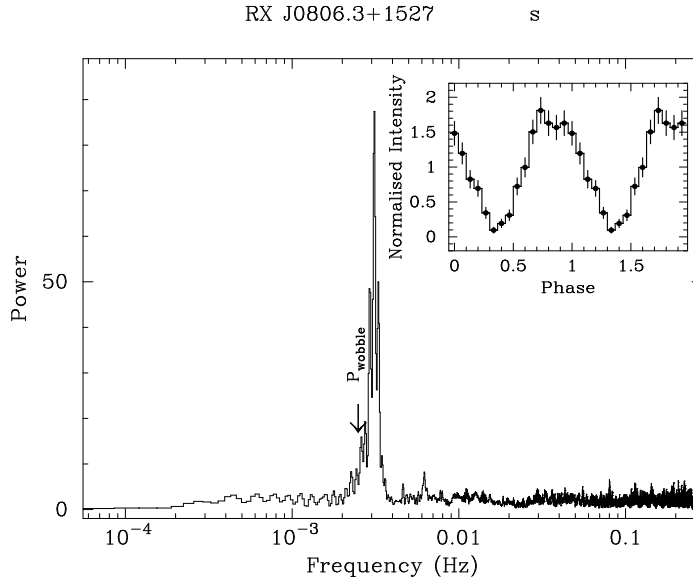


Fig. 4. The average power spectra obtained for RX J0806.3+1527 light curves by using both HRI observations (ROR 300421n00 and ROR 300421a01). The highly significant peak ($\sim 9\sigma$ based on the fundamental only) was found at a frequency of 0.0031127 Hz, corresponding to a period of 321.25 s. The frequency of the wobble is marked with a vertical *solid arrow*. The RX J0806.3+1527 light curves folded at the best period (321.25 s) is also shown in the little upper right panel

We have extracted a sample of cluster candidates based purely on the source extension (see Fig. 3), which was requested to exceed the local PSF at more than $\sim 5\sigma$ level. These candidates (limited to $|b_{II}| > 20^\circ$ and with flux brighter than $f_x \sim 3 \cdot 10^{-14}$ erg s $^{-1}$ cm $^{-2}$) have been screened by coupling the X-ray isophotes to the DSS2, discarding 20% of them as obvious contaminants. About 90 objects in the current “clean” sample of candidates are already identified on the DSS with clear groups or clusters, while the remaining ~ 300 “blank-field” objects need dedicated imaging follow-up work. This is currently underway using the TNG and ESO 3.6 m telescopes and we show one example in Fig. 5. It is among these “invisible” objects that the highest-redshift clusters in this sample are certainly hidden. The success rate of the identification program is so far high, with 80% of the ~ 20 targets observed providing a positive identification.

A quantitative comparison of the BMW cluster sample properties to those of existing surveys is given in Fig. 6, where the sky coverage at different flux limits is plotted. The large sky coverage, nearly 3 times that of the

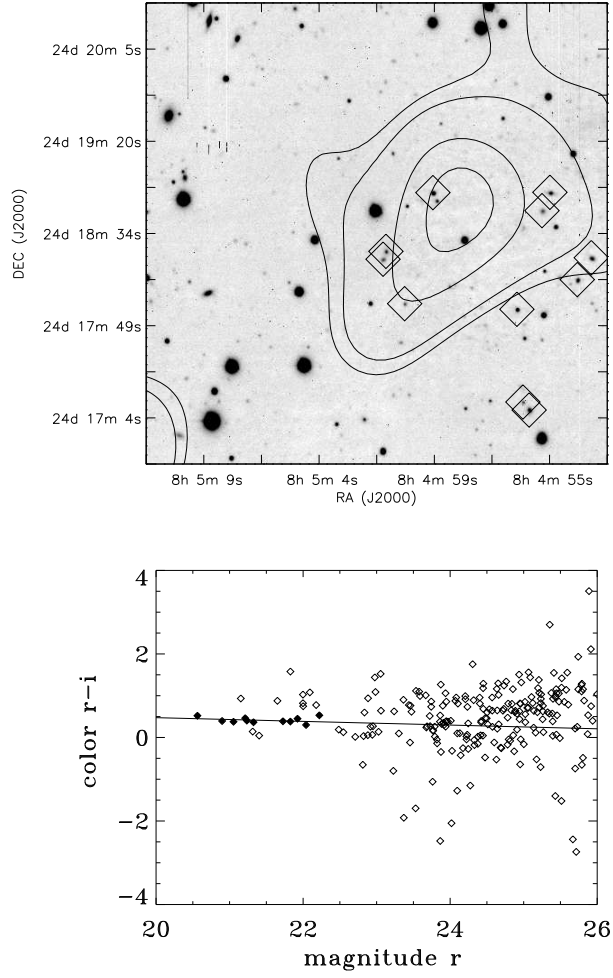


Fig. 5. bot panel: Colour-magnitude diagram of the cluster BMW080459.3+241, showing a concentration of the brighter galaxies (solid bullets, $r < 22.5$) around a similar colour. The sky distribution of these galaxies is marked in the **top panel** over a 100 min image taken with the TNG telescope. The red-sequence colors suggest a tentative redshift $z \simeq 0.6$.

CfA PSPC sample, makes the BMW cluster sample an excellent source for finding luminous clusters and thus verify the indications for evolution of the XLF bright-end yielded by the EMSS and PSPC samples.

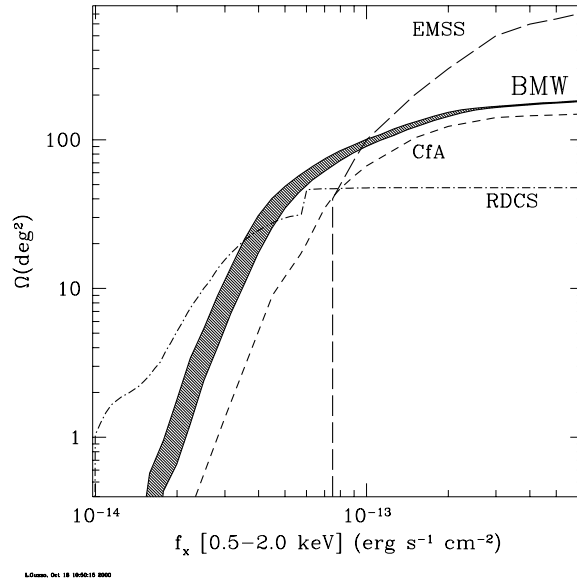


Fig. 6. The solid angle covered by the BMW cluster sample at different fluxes compared to the EMSS survey (Gioia et al. 1990) and two PSPC surveys (CfA: Vikhlinin et al. 1998b; RDCS: Rosati et al. 1998).

2.3 Cross-correlations

The sharp core of the ROSAT HRI Point Spread Function (< 6 arcseconds FWHM on-axis) greatly simplifies the search of counterparts at different wavelengths, providing valuable information for source identification. As first examples we present in Fig. 7 the cross-correlations of the BMW catalogue with the following catalogue: (i) a preliminary version of the Guide Star Catalog II (GSC-II); (ii) the Infrared IRAS point source catalogue; (iii) the NVSS catalogue at the radio wavelengths; (iv) the ROSAT source catalogue of HRI pointed observations (ROSHRICAT) delivered by the ROSAT Consortium.

The cross-correlation with the GSC-II is still preliminary since the optical catalogue does not cover all the sky yet. As soon as the GSC-II will be completed the cross-correlation will be repeated as well. The cross-correlations of the BMW catalogue with the four catalogue provide the following results: $\sim 10,000$ cross-correlated objects with the GSC-II, ~ 400 with the IRAS catalogue, ~ 500 with the NVSS catalogue and finally ~ 6400 with the ROSHRI catalogue.

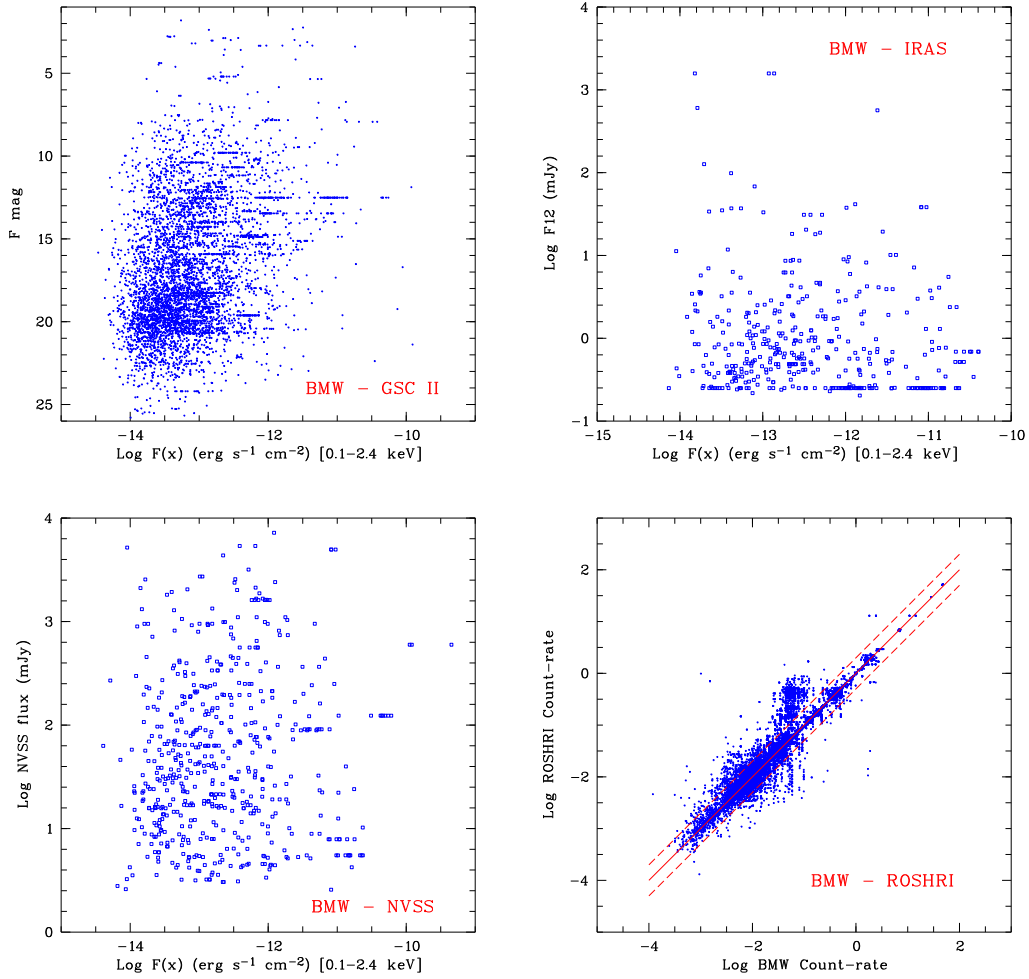


Fig. 7. **upper left panel:** GSC-II B magnitude versus the BMW X-ray flux (0.1–2.4 keV) for the ~ 10000 cross-correlated objects (10 arcsec cone radius); **upper right panel:** IRAS flux (at $12 \mu\text{m}$) versus the BMW X-ray flux for the ~ 400 cross-correlated objects (1 arcsec cone radius); **lower left panel:** NVSS flux (at 20 cm) versus the BMW X-ray flux for the ~ 500 cross-correlated objects (1 arcsec cone radius); **lower right panel:** ROSHRICAT count rate versus the BMW count rate for the ~ 6400 cross-correlated objects (1 arcsec cone radius). The two dashed lines represent the region in which the count rate is within a factor of two.

2.4 The On-line Service

A WEB based browser to access the service of the BMW catalogue has been developed at the Osservatorio Astronomico di Brera. The source by coordi-

nate environment allows the search by object name or coordinates and to choose the output format (table only or table and sky chart). The WEB site can be found at:

<http://vela.merate.mi.astro.it/~xanadu/browser/sbmw.html>.

If you need to get in touch with us write to: xanadu@merate.mi.astro.it.

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